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REVIEW

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Point-of-care ultrasound (POCUS) diagnosis of rib fractures

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Abstract

Aim To review the literature on the role of Point-of-care ultrasound (POCUS) in diagnosing rib fractures compared with other diagnostic modalities and to give recommendations on its role.

Methods Broad text PubMed database search was performed using general terms (rib, fracture, ultrasound, diagnosis) in English language without time restriction. Selected articles were critically read by three acute care physicians who have more than 20 years' experience in POCUS.

Results Ultrasound, as shown by a recent meta-analysis, had a pooled sensitivity of 89.3%, a pooled specificity of 98.4%, and a pooled positive likelihood ratio of 55.7 without difference between emergency and radiology departments. The uncertainty of evidence was high due to (1) selection bias, (2) geographical bias, and (3) heterogeneity of the operator's experience. POCUS has certain advantages including: (1) it is *dynamic* so it can evaluate the rib displacement during respiration, (2) It is *portable* so that it can be used in prehospital setting and disaster situations, (3) it has *no risk of radiation* so that it can be used in pregnant women, children, and in repeated follow-up, and (4) it has good resolution to evaluate the soft tissues around fractures. In contrast, its limitations include: (1) it is operator dependant, (2) it takes a longer time, (3) it cannot diagnose ribs covered by bones like those under the scapula, and (4) it needs a conscious patient to guide the examination. Ultrasound-guided blocks, including intercostal nerve block, serratus anterior plane block, and erector spinae plane block were successful in controlling the pain of multiple rib fractures.

Conclusions This review supports the use of POCUS in diagnosing rib fractures, which can be extended into ultrasound-guided blocks for pain control. Nevertheless, it highlights the need for research with higher quality in this area. Ultrasound and CT scan should be complementary and not competitive.

Keywords Chest X-ray, Computed tomography, Diagnosis, Fracture, Management

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Introduction

Rib fractures are commonly encountered in blunt chest trauma. Patients who have multiple or displaced rib fractures have an increased risk for hemothorax, pneumothorax, and lung contusion. Those who have 10-12th rib fractures are more prone to splenic and hepatic injuries [1, 2]. A rib fracture has cortical disruption. It is classified as *nondisplaced* when it keeps its alignment, and as *displaced* when it has an alignment abnormality [3]. Historically, radiological investigations to detect rib fractures did not attract major attention. In 1982, De Luca et al. stated that " *radiographs obtained solely to detect fractures are not warranted, but a posteroanterior chest film is necessary to assess pleural or pulmonary complications of chest trauma*." [4]. This view changed over time as attention was taken towards pain control and avoiding missed injuries, which have medicolegal implications. This is more important in elderly patients who are more prone to pulmonary complications [5].

Conventional chest X-ray (CXR) has been the recommended modality in diagnostic guidelines for suspected rib injuries in minor chest trauma both by the American College of Radiology and Canadian Association of Radiologists [6, 7]. Notably, CXR may fail to detect a substantial portion of rib fractures, especially those that are subtle or non-displaced [8]. Reliance on CXR to detect rib fractures continues despite evidence suggesting using other diagnostic tools like Point-of-care ultrasound (POCUS). Over the past four decades, the refinement of POCUS has markedly altered its diagnostic role. POCUS offers distinct advantages over other radiographic imaging. It does not expose patients to ionizing radiation, it is portable for bedside use, and can be performed rapidly, factors that are critical in hemodynamically unstable patients [9, 10]. Low-cost, affordable handheld POCUS machines are now widely available. Furthermore, hands-on and online POCUS training courses are increasingly available to all, including undergraduate medical students as part of their basic medical training [11, 12]. We aimed to review the literature on the role of POCUS in diagnosing rib fractures compared with other diagnostic modalities to give recommendations on its role.

Methods

Text search using general terms was performed on 6th August 2025 by the first author (FAZ) using the PubMed database to achieve a wide range search. The general terms used were (fracture, rib, ultrasound, diagnosis) without time, type, or language restriction. Titles were browsed and relevant ones were selected; abstracts of these articles were read; selected articles were retrieved through the National Medical Library of the United Arab Emirates University [13]. Further articles were selected from the reference lists of the read articles; three of these were in German and one in Italian. These articles were translated, section by section, into English using https://www.deepl.com/en/translator. Since we planned to write a narrative review, we had no protocol for this review. Selected articles were classified and divided between three acute care physicians who have more than 20 years' experience in clinical POCUS. The articles were critically read, summarized, and drafted into their relevant sections. Finally, the first author critically read, organized, restructured, and repeatedly edited the drafted material. Illustrations were drawn or retrieved from open-access sources as needed.

Results

Basic ultrasound physics

Ultrasound transducers emit high-frequency sound waves that travel through the human body and interact with anatomical structures. The nature of this interaction varies depending on the acoustic impedance of the tissues. High-density structures (such as bones) have high impedance and will reflect a strong echo to the probe. These will produce bright images on the screen with a black shadow behind them (like the ribs). Low-density structures (such as hemothorax) have low impedance and will allow most waves to travel through, reflecting only a weak signal to the probe. Accordingly, fluids will be black on the screen. In between, fibrous tissues will be white without a shadow (like the diaphragm), soft tissues will be grey (like the liver), while gas will have a reverberation artefact (like the lung) (Fig. 1) [14–16].

POCUS technique in detecting rib fractures

High-frequency 7–12 MHz linear transducers should be used. The high resolution of the produced images gives more detailed information regarding the sonographic changes of soft tissues around the fractures [5]. Operators should examine suspected regions based on pain localization, and patient-guided palpation during scanning, thus narrowing scanning windows and expediting diagnosis [10, 17, 18]. Scanning should include approximately 10 cm around the maximum tender point [19].

Ask the patient to point towards the maximum point of chest wall pain. At the midclavicular line, count the ribs from the top just below the clavicle (second rib) downwards until you reach the targeted rib. This procedure will locate the suspected fractured rib (Fig. 2A). Start initially by putting the probe at 90 degrees across the rib with the marker pointing up (Fig. 2B). You can examine the pleural movement or the presence of hemothorax at this view. The normal anatomical structures of this section from superficial to deep, through the intercostal space, will be skin, subcutaneous fat, subcutaneous fascia, chest wall muscles, intercostal muscles, pleura, and lung (shown as reverberation artefact) (Fig. 3) [20].

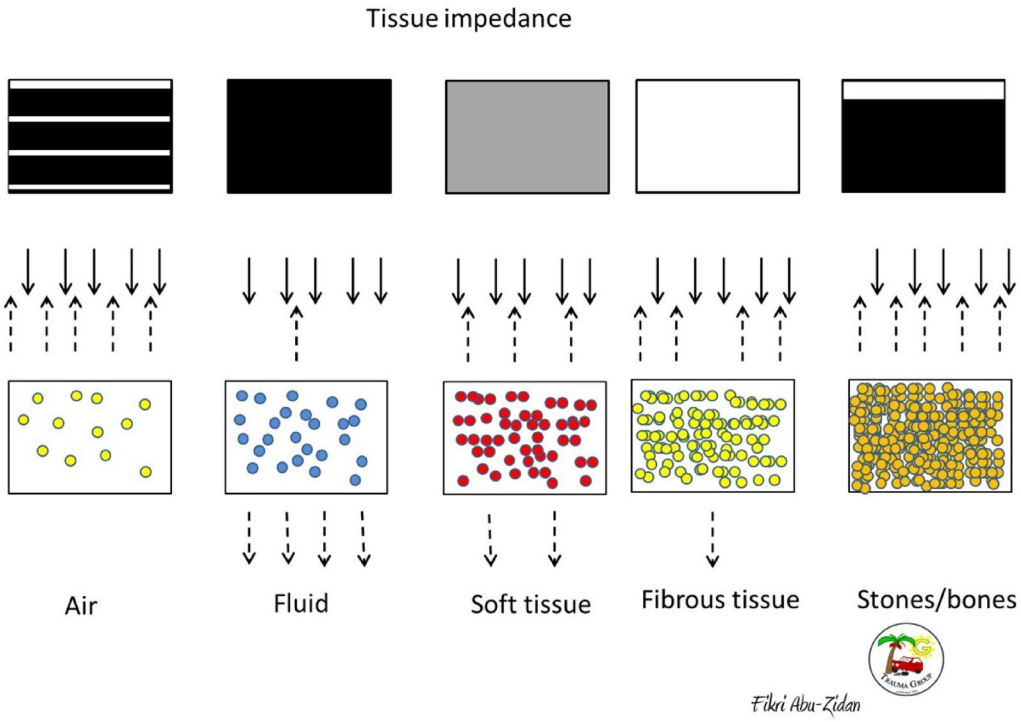

Fig. 1 An illustration showing the tissue impedance and related reflection of ultrasound waves. Denser tissues reflect more ultrasound waves. Accordingly, fluids are black, soft tissues are grey, fibrous tissues are white without a shadow, and solid structures are white having a shadow behind them. Air has a reverberation artefact. Reproduced from *Abu-Zidan and Cevik*, *World J Emerg Surg*, *2018;13:47* which is distributed under the terms of the Creative Commons Attribution 4.0 International License

Fig. 2 An illustration showing the POCUS technique in detecting a right 6th fracture rib in a simulated patient. Ask the patient to point towards the maximum point of chest pain (X). Calculate the rib's number in the midclavicular line from below the clavicle (second rib) till you reach the targeted rib **A**. Locate the probe 90 degrees across the rib with the marker pointing up (white arrow) **B**. Rotate the probe 90 degrees anticlockwise with the marker directed to the right of the patient (white arrow) perpendicular to the rib surface over its longitudinal axis. Put your index and thumb in the intercostal spaces leaving the targeted rib to be examined in between them **C**. Swift the probe medially and laterally to examine the entire rib **D**

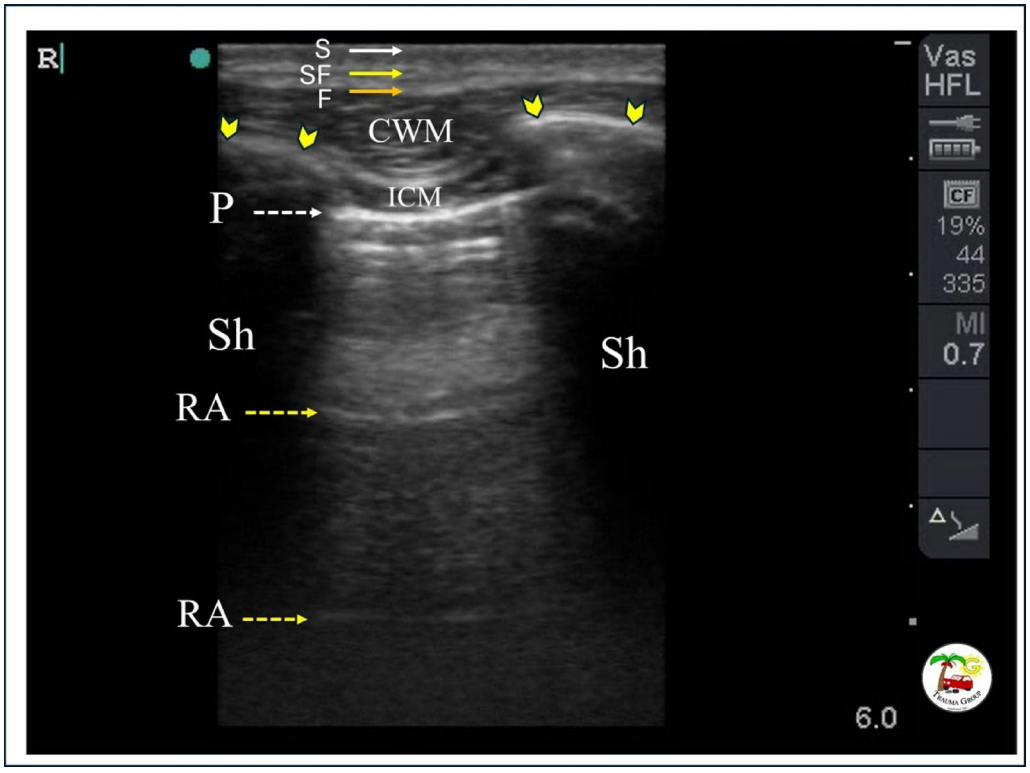

Fig. 3 Normal anatomical structures of a sagittal section 90° across the ribs. The structures shown starting from the skin through the intercostal spaces are skin (S), subcutaneous fat (SF), subcutaneous fascia (F), chest wall muscles (CWM), intercostal muscles (ICM), pleura (P), and lung (shown as reverberation artefact (RA). You can see the ribs lateral to the intercostal space on both sides as hyperechogenic white lines (yellow arrow heads) with shadow artefact (Sh) behind them. (The POCUS study was performed and interpreted by Professor Fikri Abu-Zidan)

Bordering the intercostal space on both sides, you will see the hyperechogenic white lines with shadow behind them representing the ribs. Rotate the probe 90 degrees counterclockwise with the marker directed to the right of the patient to be perpendicular to the rib surface over its longitudinal axis. Put your index and thumb in the intercostal spaces, leaving the targeted rib to be examined in between them, giving space for the ultrasound probe (Fig. 2C). Observe the continuous smooth hyperechoic cortex; any displacement or discontinuity suggests a fracture [17, 18]. Slide the probe medially and laterally with the marker directed towards the right to examine the entire rib (Fig. 2D) [5].

Instructing patients to briefly suspend respiration at the end of expiration during scanning improves the quality of images. This technique stabilizes both the chest wall and pleurae, enabling more precise delineation of subtle cortical irregularities [21, 22]. In painful thoracic injuries where holding breath is not feasible, acquiring short cine loops allows frame-by-frame selection of moments with minimal motion blur for interpretation that can be reviewed later [17, 22]. Moreover, changes during respiration or with positional adjustments can be observed instantly, helping differentiate between true cortical breaks and artefact patterns from overlying pleural surfaces [22].

Sonographic findings of rib fractures

Characteristic sonographic findings in rib fractures arise from disruption of the normal smooth, hyperechoic cortical line that defines an intact rib surface [18, 23]. The defect can be seen as a sharp cortical step-off if there is a displacement, or as a narrow separation without significant offset in nondisplaced fractures (Fig. 4A–C) [8, 22]. Subtle lesions may present as an angular deviation of the cortex without an obvious gap, which highlights the necessity for slow, deliberate probe movement across suspect zones [24]. Direct evidence of a fracture is often accompanied by secondary findings that reflect acute injury. Among these, subperiosteal hematoma is notable, appearing as a hypoechoic area that separates the lifted periosteum from the underlying cortex (Fig. 5) [8, 9]. Hematomas may organize within days into more heterogeneous echotextures [9]. Localized soft tissue edema surrounding the injury site adds another indirect indicator; it increases scatter and reduces definition of adjacent muscle layers while sparing deeper pleural reflections [8]. These changes are especially apparent in longitudinal

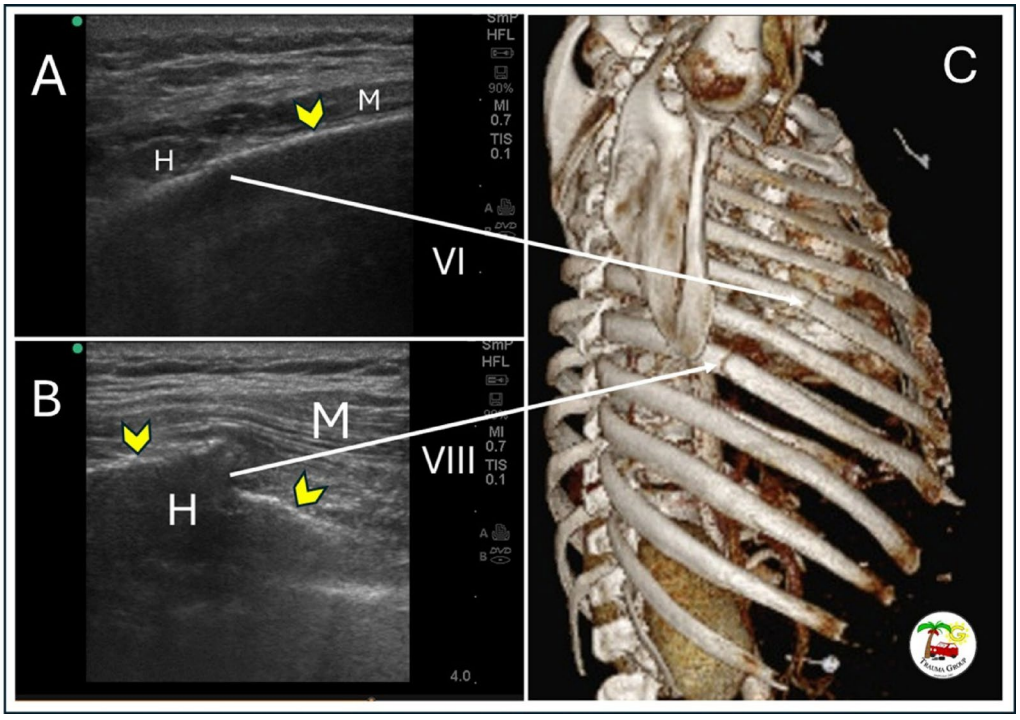

Fig. 4 48-year-old male pedestrian who was hit by a 4-wheel car to his right side. He was thrown away for 8 m. He sustained head, chest and pelvic injury. He was hemodynamically stable. EFAST showed right pleural effusion. POCUS could demonstrate right 6th (**A**) and 8th rib (**B**) fractures but not a first rib fracture because of lack of a sonographic window. CT scan has confirmed these findings (**C**). Yellow arrows, outer cortex of a rib, H = hematoma, M = muscle. Note that the sixth rib is not displaced while the 8th rib is displaced. The ultrasound is dynamic changing between inspiration and expiration. The displacement was more pronounced during inspiration compared with CT scan. Furthermore, notice that the muscles are thicker near the angle of the scapula (The POCUS study was performed and interpreted by Professor Fikri Abu-Zidan)

scans, where muscle fiber orientation creates echogenic striations that are disturbed by interstitial fluid [8, 9, 25].

Fracture displacement can be graded by ultrasound through measuring the cortical offset in millimeters along the long-axis view. Mildly displaced fractures show offsets comparable to the thickness of the echogenic line itself (about 1 mm). Moderate displacement measures 2–4 millimeters while severe displacement exceeds 4 mm with visible fragment separation [23]. The accuracy of this quantification depends on aligning the beam perpendicular to the cortex at its discontinuity to avoid artefacts. Within one week post-injury, hypoechoic peri-fracture zones dominate due to hematoma and early granulation tissue. By weeks two to three, trabecular bridging appears as irregular, thickened echogenic material that spans cortical gaps, marking the earliest sonographic representation of callus formation [9]. With time, the echogenic bridging becomes more uniform and starts to cast acoustic shadows like native cortex as the mineralization process increases. This progression can be monitored during follow-up scanning to evaluate healing velocity.

Pleural motion deep to an injured rib remains identifiable unless complicated by pneumothorax; absence of pleural sliding beneath a fractured segment suggests associated pleural breach or pneumothorax [9, 22, 26]. Anechoic pleural collections adjacent to fracture ends indicate hemothorax or effusion [26]. Reverberation artefacts, referred to as "chimney phenomena," may occur near incomplete fractures due to trapped air between slightly separated cortices, which causes sound to reflect repetitively [9, 10, 27]. Furthermore, a linear edge of a shadow artefact may appear posterior to the fracture [5, 27].

False positive results may occur when scanning obliquely across intercostal spaces, resulting in apparent line gaps. Confirming suspected defects by scanning at the vertical plane helps to confirm the diagnosis [22, 28]. Similarly, age-related calcification spots within cartilage produce isolated hyperechoic foci which should not be mistaken for displaced fragments unless confirmed by other traumatic signs such as local edema or hematoma [10].

Costal cartilage and sternal fractures

CXR routinely misses costal cartilage disruptions or small cortical step-offs obscured by overlapping anatomy. Ultrasound was useful in detecting costal cartilage fractures in mild blunt chest trauma, which were missed by CXR and computed tomography (CT) scan [29]. Targeted ultrasonographic scanning can reveal discontinuity

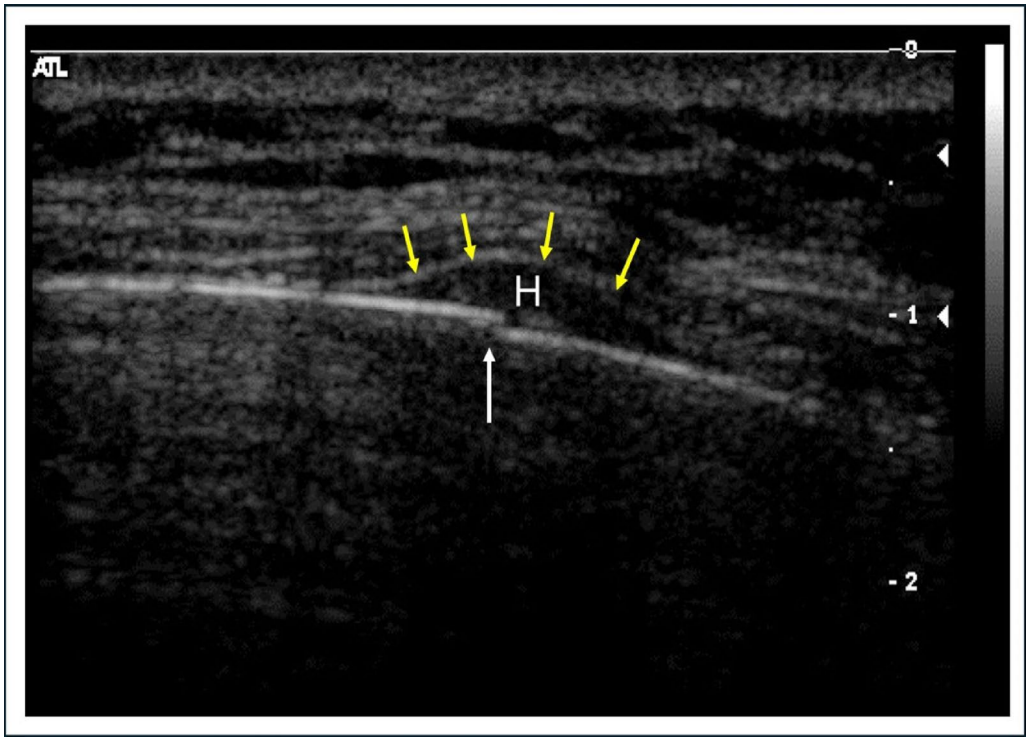

Fig. 5 A sonographic image showing a cortical disruption of a fractured rib (white arrow), subperiosteal hematoma (H), and periosteum (yellow arrows). Reproduced, and modified from *Hwang and Lee, J Exerc Rehabil, 2016;12:637–641*. which is published under the terms of the Creative Commons Attribution CC BY 4.0 International License

of the thin anterior echogenic line of the hypoechogenic cartilage, step-off, hyperechoic interruptions of the cortical line accompanied by acoustic shadowing or localized periosteal irregularity along their typically hypoechoic profile relative to bone [24, 30, 31] Because cartilage lacks the dense reflectivity of cortical bone, step-offs here may be more subtle, requiring careful gain optimization to avoid obscuring fine margins [22, 24]. Normal variants at the costochondral junction, such as a slight angulation or a narrow gap without callus, can resemble pathology. Correlation with tenderness location and a contralateral comparison assists in diagnosis [22].

In a study assessing sternal and rib fractures, Ultrasound achieved diagnostic sensitivity near 90% versus roughly 15% for chest radiography [22]. This sensitivity advantage extends to chondral injuries, areas invisible on radiographs unless calcified, where sonographic visualization shows even fine contour disruptions along costochondral junctions [31, 32]. Jin et al. compared conventional radiography with ultrasound in 50 patients with suspected sternal fractures. Sonographic diagnosis of sternal fractures was defined as "*discontinuity and a bony defect in the sternal cortical margin with or without soft tissue haemorrhage or swelling*" [33]. Radiology could diagnose sternal fractures in only 12 patients (24%) compared with 31 patients (62%) by ultrasound. Unfortunately, there was no gold standard test (CT scan) to calculate the sensitivity and specificity in this study.

POCUS advantages

POCUS has emerged as a valuable option for the evaluation of rib fractures, combining non-invasiveness with the capacity for rapid, real-time imaging directly at the patient's bedside [9, 26, 32]. Ultrasound is a dynamic study which can be done through the whole respiratory cycle enabling it to properly evaluate the rib displacement [34]. Unlike ionizing radiation-based modalities, POCUS avoids dose-related risks, an advantage that becomes especially meaningful when repeat assessments are anticipated [35]. Accordingly, it can be used in groups who have a high risk of being affected by radiation, such as children and pregnant women [19, 35]. Furthermore, this encourages its integration into follow-up protocols to track fracture healing progression without cumulative exposure concerns recognizing those with delayed union [22, 36, 37].

POCUS portability allows deployment in critical care environments, emergency departments, or even during prehospital care without delaying ongoing treatment measures [26, 38]. In settings where other radiological diagnostic tools like CT scan and CXR are not available, like earthquake disasters associated with complete or partial destruction of hospitals [39], POCUS will be very

useful in diagnosing fractures [40]. This enables frontline providers who are trained in POCUS rib scanning to generate reliable findings that can significantly support triage algorithms [17, 26, 28].

POCUS can help grade fracture displacement severity in real-time according to measurable cortical offset [23]. Such quantification can inform expectations regarding pain duration and respiratory compromise risk. Furthermore, POCUS can assess both fracture status and immediate thoracic complications in one bedside session supporting integrated decision-making without recourse to multiple imaging modalities [9, 25].

POCUS limitations

POCUS has multiple limitations. Operator skill determines image acquisition quality and diagnostic accuracy. Inexperienced practitioners may overlook subtle anterior fractures or misinterpret normal anatomical variants as pathology [9, 17, 23]. Proper training and credentialing are central to the success of POCUS implementation. Furthermore, bedside POCUS should be well-documented in the medical records. This will ensure that operators will be more committed to their POCUS examination, which will also close their learning loop when they compare their results with the final diagnosis. Furthermore, they should indicate how it helped them in their clinical decisions. Proper record documentation will support clinical research to better refine the role of POCUS in clinical practice [41].

Excessive subcutaneous tissue, fat, or large breasts can reduce the resolution of deeper structures and limit the POCUS assessment [9, 22, 34]. Anatomical positioning may also pose challenges for a complete investigation. Posterior arcs of ribs adjacent to scapular shadows require angulation or patient repositioning. Furthermore, the infraclavicular portion of the first rib and parts of the ribs that are under the scapula may not be accessible for sonographic examination [5, 31, 34].

Artefact recognition represents another important consideration. For example, normal pleural lines can simulate cortical irregularity under certain beam angles if comet-tail artefacts are absent due to local lung pathology rather than fracture [22]. Furthermore, the presence of excessive subcutaneous air in the chest wall will hinder the ultrasound examination. Awareness of these pitfalls demands correlation with clinical findings and sometimes complementary imaging if uncertainty persists.

Unconscious patients cannot locate the maximum point of tenderness; CXR and CT scan will be the alternative diagnostic tools in this situation. Furthermore, sonographic scanning of suspected rib fractures can be painful and time-consuming (around 15 min). It should not distract or delay the trauma resuscitation process [5, 34]. It may be considered as part of the secondary survey in a hemodynamically stable patient after an extended focused assessment sonography of trauma (EFAST) was negative. Exclusion of life-threatening conditions is more important than the diagnosis of rib fractures [20]. Nevertheless, it may be useful as part of a tertiary survey to reduce missed injuries when a patient is re-evaluated in the ward. Finally, CT scans should be done when there is high clinical suspicion of a rib fracture following a negative ultrasound study.

Ultrasound compared with radiography

A direct comparison between ultrasound and conventional radiography for the detection of rib fractures consistently reveals a higher sensitivity for ultrasound, particularly in identifying subtle or nondisplaced cortical injuries [10, 22, 25]. Radiographs are limited by their dependence on optimal projection angles and the challenge of visualizing ribs through superimposed anatomical structures [31]. Overlapping scapular, clavicular, and pulmonary anatomy frequently obscures fracture lines, particularly for posterior and upper ribs [23]. Sonographic resolution at superficial depths enables visualization down to fractions of a millimeter of cortical displacement, whereas radiography requires more separation between fragments for detection [22, 23]. Furthermore, ancillary findings are not visible on radiographs until much later, when callus becomes dense enough to change X-ray outlines [23]. Therefore, an injury imaged within hours or days may be readily confirmed via ultrasound, while radiographic films remain apparently negative until a periosteal reaction develops weeks later [32], which necessitates re-imaging if relying solely on CXR. Radiography retains some advantages in the initial trauma survey context: it can identify concurrent thoracic pathology, such as a large pneumothorax or hemothorax, during the same acquisition that assesses gross bony disruption [18]. Posterior arcs of ribs obscured beneath scapular shadows remain one exception where projection imaging may still document fractures missed on routine anterior rib scanning unless operator technique is adapted [10, 22, 24]. Skilled sonographers can utilize alternative acoustic windows, such as supraclavicular fossa entries for upper posterior ribs or paraspinal positioning for lower arcs, to visualize lesions that would otherwise require X-ray confirmation [24, 36]. Patients with localized chest wall tenderness, but negative CXR should be considered for bedside ultrasound. Time taken for an experienced operator to perform targeted rib ultrasound is competitive with conventional radiography acquisition plus processing time [10]. When portable CXR equipment is stationed centrally while patients await in busy departments, an immediately available ultrasound machine allows diagnosis without delays [9, 32]. This mobility advantage becomes more apparent

in prehospital scenarios or intensive care settings where patient movement involves risk [10]. Radiation exposure from CXRs, though relatively low compared to CT, remains cumulative over repeated studies. Ultrasound avoids this entirely, making it preferable for cases necessitating serial monitoring [23]. This is particularly appropriate in pediatrics and pregnant women, where non-ionizing approaches are prioritized whenever feasible. One element in favor of radiography over ultrasound is its reduced operator dependency. Interpretation of standard AP/PA films has been part of foundational medical education for decades and is relatively uniform among trained clinicians [8, 38]. Ultrasound interpretation quality varies widely with examiner experience [10]. Standardizing scanning techniques with structured protocols helps mitigate variability and narrow performance gaps between expert and intermediate sonographers.

Ultrasound compared with CT scan

CT scan allows for a comprehensive evaluation of the rib cage, effectively identifying fractures in any location, including those situated in posterior arcs that are obscured by scapulae or deep costovertebral joints, which may affect sonographic windows [9]. Its ability to show spatial relationships across all ribs simultaneously also facilitates assessment of fracture counts and distribution with high precision, an important consideration in prognostic scoring or flail chest diagnosis, or preoperative planning for rib fixation [28, 38]. However, CT scanning poses certain challenges such as patient transferal to dedicated imaging suites, the interruption of continuous monitoring, and radiation exposure [17]. Additionally, CT can identify extra fractures that do not alter management for stable patients; therefore, the benefit of increased sensitivity must be balanced against the associated risks and logistical challenges [28]. Ultrasound cannot match CT for visualizing deep intrathoracic structures or subtle marrow-level changes obscured beneath aerated lung. Nonetheless, within its penetration limits, high-frequency probes can pick up minimal displacements along anterior and lateral ribs, areas accessible without interference from overlying bone, sooner than CT in many acute settings [9]. This immediate availability is particularly valuable where the mechanism of injury suggests isolated thoracic wall trauma without accompanying visceral injury [32]. Furthermore, ultrasound allows targeted interrogation based on patient-localized tenderness [17, 32]; conversely, CT evaluates all segments indiscriminately but often takes long time to obtain and interpret [26]. The portability of ultrasound makes it adaptable to prehospital and bedside settings where CT is simply unavailable. In resource-limited settings without a CT scan facility, it can be the only possible modality for timely fracture confirmation, especially in disaster situations [38, 40]. Even in tertiary centres, ultrasound can precede CT as a triage tool, identifying clear-positive fractures rapidly and may prevent further imaging if clinical suspicion for deeper injury is low and vital signs are stable [9]. The selectivity here arises from understanding risk-benefit balances, reserving CT's extensive capabilities for complex multi-trauma patients when ruling out accompanying intrathoracic problems becomes crucial. Table 1 compares ultrasound with CT scan in diagnosing fractured ribs. Ultrasound and CT scan should be seen as complementary diagnostic studies and not competitive.

Table 1 Comparison between ultrasound and CT scan in diagnosing rib fractures

Question	Ultrasound	CT scan
Where	The machine goes to the patient (bedside) Emergency Department, ICU, Prehospital and disaster situations	The patient goes to the machine Radiology suit
When	Any time as much as needed, Useful in tertiary survey to reduce missed injuries	When patients are stable Unconscious patients Used for secondary survey
Who	Skilled knowledgeable operator	Standardised technique
Why	Portable, easy, cheap, less radiation, affordable to low-income countries	Fast, can evaluate all ribs, examines the whole patient at the same time
What (indications)	Pregnant women and children CT scan not available Elderly with mild chest trauma and localized tenderness. Persistent chest tenderness and a negative CT scan Follow up of callus formation	Multi-trauma patients Used with high level of caution in pregnant women and children
How	High frequency linear ultrasound probe (7–12 MHz) on maximum tender chest point, led by the patient, located on the surface of the rib longitudinally and perpendicular to its surface.	Trauma protocol with intravenous contrast Can be tailored in certain situations to be without contrast or limited to certain regions as judged by the treating physician

Ultrasound diagnostic accuracy

There are two systematic reviews which compare ultrasound with other radiological modalities. Battle et al. in 2019 [34] compared ultrasound with chest radiography. They searched four databases and grey literature without time or language restrictions. They included 13 studies in their review; all were of low quality, high risk of bias, or concerns regarding applicability. Although ultrasound seemed to be superior to chest radiography, as 11 studies

reported higher diagnostic accuracy for detecting rib fractures, the uncertainty of the evidence hindered the authors from recommending the use of ultrasound in diagnosing rib fractures [34].

Gilbertson et al. in 2022 [42] in a meta-analysis compared ultrasound with CT scan for diagnosing rib fractures. Out of 1660 published articles, they selected seven for qualitative synthesis and six for a meta-analysis, which included 663 patients. Ultrasound had a pooled sensitivity of 89.3%, a pooled specificity of 98.4%, a pooled positive likelihood ratio of 55.7 and a negative likelihood ratio of 0.11. There was no statistical difference between the emergency and radiology departments in diagnostic accuracy. This study had major limitations, including: (1) selection bias that could have contributed to the high pooled sensitivity. Only one study included consecutive patients based on personal judgement; (2) geographical bias, out of the 7 studies included, 5 were from Egypt and Turkey; (3) heterogeneity of the operator's experience; and (4) heterogeneity in the used techniques [42]. This study clearly supports the use of ultrasound in diagnosing rib fractures. Nevertheless, its high level of uncertainty indicates the need for higher quality of research to increase the evidence level and refine the role of ultrasound in diagnosing rib fractures.

Experimental models

Harding et al. [43] have recently developed an experimental dog cadaver rib fracture model to test for the accuracy of ultrasound. Ultrasound had good diagnostic ability with a sensitivity and specificity of 83% and 99%, respectively. Nevertheless, it took longer time to perform compared with reading a chest radiograph (mean of 26 min compared with 3 min) [43]. In contrast, the results of Greenstein et al. [44] who used a human cadaver model in 4 cadavers were not encouraging. Ultrasound had a sensitivity and specificity of only 50% and 60%, respectively. The positive and negative predictive values were poor (55.2% and 54.3% respectively) [44].

Special groups

Neonates

Liu et al. studied the role of ultrasound in diagnosing newborn fractures in 52 infants. Ultrasound had a sensitivity of 100% in diagnosing fractures. There was major selection bias in the study as patients were selected based on their high suspicion of presence of fractures [35]. Nevertheless, it was noticed that the images of the article were of high quality (Fig. 6). The bony layers of the ribs were detailed demonstrating both the outer and inner cortex layers beside the medulla, indicating that ultrasound waves can easily penetrate the infant bones compared with adults which supports its use in detecting fractures in infants [35].

Geriatrics

For older adults who fall and can't stay flat for a long time during a CT scan due to health issues or trouble breathing, ultrasound is an option that helps with diagnosis while maintaining patient comfort [10, 26]. Those patients usually have low energy trauma of their chest wall. POCUS has clear advantage in this group as it can be useful when the pain is localized in diagnosing the rib fractures, excluding pneumothorax, hemothorax, and intraperitoneal fluid especially when the patient is hemodynamically stable presenting few days after injury (Fig. 7A, B).

Oncology patients

High-resolution ultrasound can differentiate between rib fractures and rib metastasis. Paik et al. [45] compared the sonographic findings in 37 patients with proven rib fractures and 18 patients with proven bone metastasis. They found that sonography could properly classify 94% of patients with rib metastasis and 97% of patients with rib fractures. Metastatic lesions were characterized by bone destruction and mass formation while fractures were characterized by cortical disruption, deformity (stepping or angulation) or callus formation [45].

Table 2 summarizes the sonographic findings of fractured ribs encountered in the presented cases of this review (Table 2).

Artificial intelligence in rib fracture

Artificial intelligence (AI) applications of ultrasound have mainly been in cardiology [46]. Nevertheless, it is expected to expand to other clinical fields when properly adopted. AI can be especially useful for inexperienced doctors for fast diagnosis using small portable ultrasound machines in triage situations of disasters where CT scan or large X-ray machines may not be available. Deep learning (DL) showed utility in detection, segmentation, localisation, and classification of rib fractures. A chest X-ray may miss 50% of rib fractures, while a CT scan may miss 20% of them. Convolutional neural network (CNN) can improve the diagnosis of rib fractures by about 20% compared with a CT scan. This improvement shortened the reporting time [47]. Huang et al. used deep convolutional neural network (CNN) to diagnose rib fractures on chest X-rays. They pre-trained the available architectures such as AlexNet, GoogLeNet, DenseNet, MobileNet and CompactNet on non-medical images. The used models achieved high positive and negative predictive values and area under the curve in diagnosing fractured ribs. The authors suggested that the results are superior to humans. Incorporating CNN model into clinical practice remains challenging [48]. Zhao et al. reviewed the literature on machine learning (ML) and deep learning (DL). They concluded that CNN and recurrent neural network

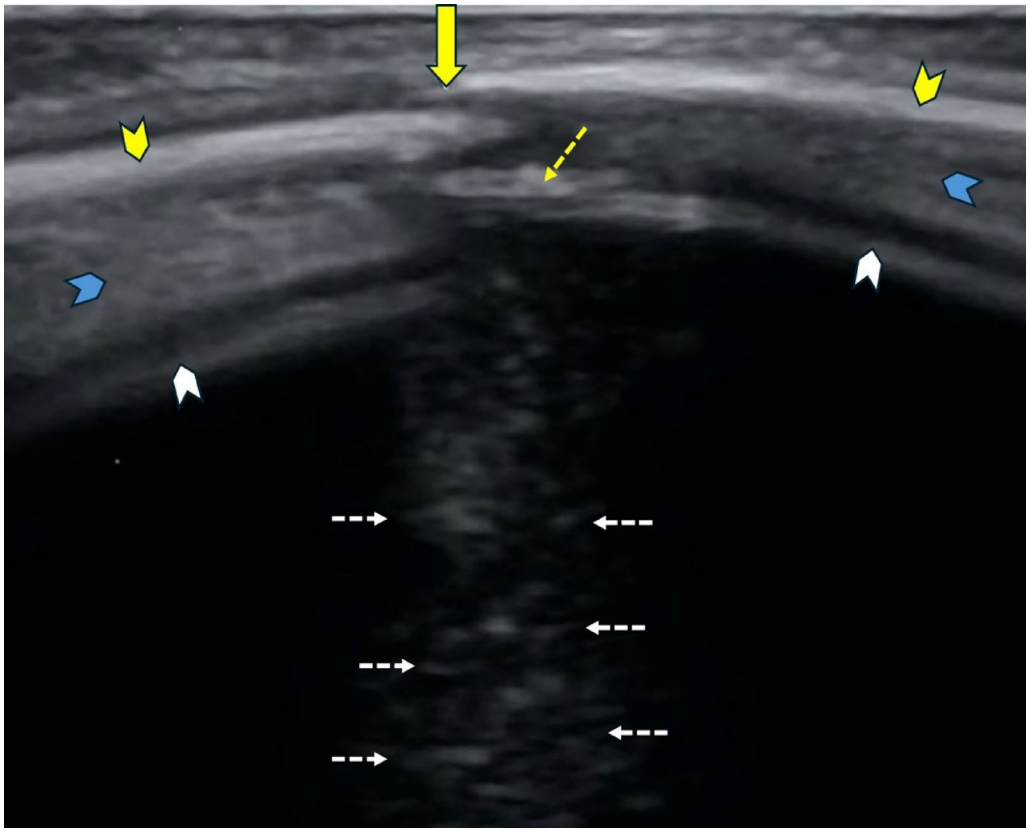

Fig. 6 Rib fracture of a 30-week gestational age infant who was delivered by a caesarean section. Forty days after birth, an ultrasound showed a fractured fifth rib on the left side (Yellow arrow). The illustration has high resolution excellent quality. It shows the bony outer cortex (yellow arrow heads), the bony inner cortex (white arrow heads), chip of bone fracture (yellow interrupted arrow), medullary bone (blue arrows), and chimney reverberation artefacts (white interrupted arrows). Reproduced, and modified from *Liu et al., Front Pediatr, 2022;10:847776* which is published under the terms of the Creative Commons Attribution CC BY 4.0 International License

(RNN) perform at the attending level of radiologists in diagnosing rib fractures. DL may work as a screening tool for thoracic injuries, thus reducing radiologist time and leading to better patient outcomes [49]. A systematic review of 27 studies evaluated the use of DL to assess detection, segmentation and classification of rib fractures using CT scan images. DL can improve rib fracture detection on CT by up to 20%. It improves radiologists' diagnostic accuracy and shortens the time of reporting, which may lead to better patient outcomes [50]. Nevertheless, multiple challenges including securing patients' personal information, establishment and enforcement of accepted ethical and legal regulations, and building the needed health informatics storage, retrieval and analytical systems must be overcome before AI is fully integrated into most clinical fields [46].

Ultrasound-guided procedures for pain control

Intercoastal nerve block (ICNB), serratus anterior plane block (SAPB), and erector spinae plane block (ESPB) are the most common ultrasound-guided blocks used in the emergency department to manage the pain of multiple rib fractures [51]. Ultrasound-guided SAPB in patients with multiple rib fractures is becoming increasingly popular among emergency physicians using it in patients who may have contraindication to a thoracic epidural [52]. Ultrasound-guided SAPB was superior to ICNB, having no complications. This was a result of identifying anatomical structures like the trapezius, latissimus dorsi, serratus anterior muscles, the fascial planes, and the thoracodorsal artery which helped avoiding the complications [53]. In a recent systematic review on emergency SAPB for various indications, including rib fractures, tube thoracostomies, herpes zoster and burns, SAPB was effective in managing anterior and lateral thoracic pain by blocking the lateral cutaneous part of the intercostal nerves. This systematic review, which included 14 studies (case reports or case series), showed significant improvements in pain control, incentive spirometer, and diaphragmatic excursion. Nevertheless, there was no RCTs; reported studies were heterogenous [54].

In a randomised controlled trial, ultrasound-guided ESPB using a high-frequency linear probe was found to reduce pain and opioid use without increased

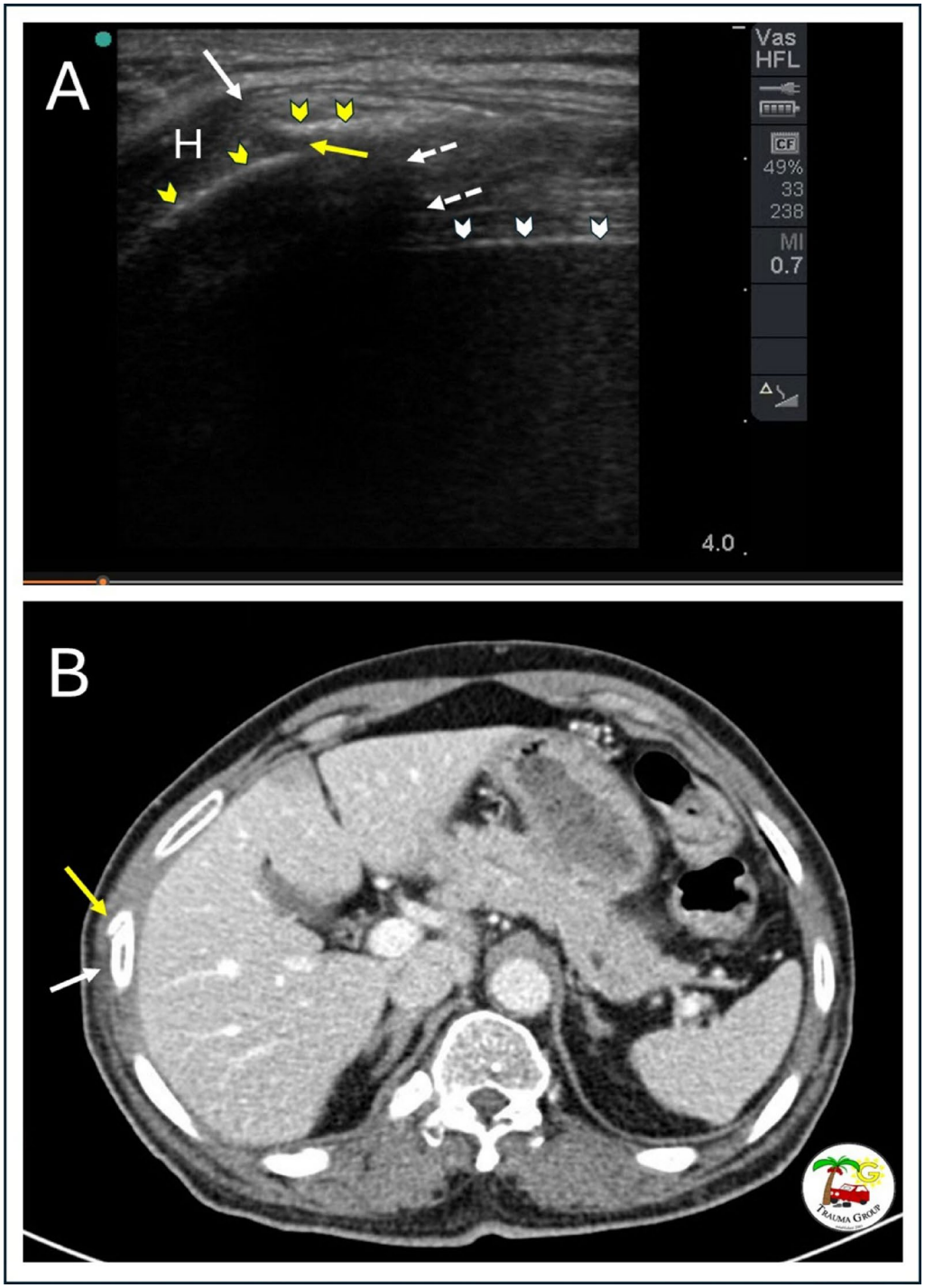

Fig. 7 85-year-old man who presented 17 days after falling on his right chest complaining of chest pain. Clinical examination revealed localized tenderness on the right side of the chest. EFAST was negative. Rib POCUS study (**A**) using a high frequency linear probe showed displaced rib fracture (yellow arrow) of the rib (yellow arrow heads), a hematoma beside the fracture (H), injured chest wall muscles (white arrow), fracture rib edge shadow artefact (interrupted white lines), and the pleura (white arrow heads. These findings were confirmed by a CT scan (**B**) which shows a fractured rib (yellow arrow) and chest wall hematoma (white arrow) (The POCUS study was performed and interpreted by Professor Fikri Abu-Zidan)

complications compared with placebo. The patients were placed in a sitting or lateral position. The spinous process of the vertebra at the level of the fractured rib was identified in a sagittal plane, and the probe was then moved 2–3 cm laterally to identify the transverse process and the erector spinae muscle [55]. Similarly, Palachick et al. [56] showed that ESPB significantly reduced the pain score and increased incentive spirometry. Nevertheless,

Table 2 Summary of the sonographic findings of fractured ribs as demonstrated in the figures of this review

Sonographic finding	Figure number
Normal findings: skin, subcutaneous fat and fascia, chest wall and intercostal muscles, pleura, ribs, and lungs.	Figure 3
Rib fractures: cortical disruption, stepping or angulation	Figures 4, 5, 6 and 7
Chest wall hematoma	Figures 4 and 7
Subperiosteal hematoma	Figure 5
Mobility of a fractured rib (instability)	Figure 4
Injured chest wall muscles	Figure 7
Shadow artefact	Figure 3
Lung reverberation artefact	Figure 3
Chimney reverberation artefact	Figure 6
Fracture rib edge shadow artefact	Figure 7

their study had many limitations, including selection bias and lack of a control group [56].

Ultrasound-guided bedside percutaneous intercostal nerve cryoneurolysis can be used for long-term pain control in patients with rib fractures who are not suitable for rib fracture stabilisation. Nerve Wallerian degeneration occurs when subjected to a temperature of – 50 to – 70 degrees Celsius [57]. Continuous ultrasound visualisation is important for safety and the prevention of tissue damage. A single blind randomised controlled trial with a small sample size, compared ultrasound-guided cryoneurolysis (n = 11) and ultrasound-guided peripheral nerve block (n = 9) for long-term pain control in patients with rib fractures. Cryoneurolysis significantly increased the inspired volume, reduced pain and the need for opioids compared with the peripheral nerve block [58]. These findings were reproduced by Forrester et al. who followed patients up to 30-days [57].

Ultrasound can be used to localise and guide surgical incisions during rib fracture fixation. It reduces incision length and operative time thus leading to better postoperative pain control [19]. Martin et al. tested the use of ultrasound localisation of the rib fractures during surgical stabilisation of the ribs. Out of 48 patients with rib fractures who had surgical fixation, 13 had ultrasound-guided fracture localisation. Patients with ultrasound localisation had smaller incisions, shorter operative time and better postoperative pain control at follow-up compared with those who did not. This study has several limitations, including the historical comparison, the small sample size, differences in the proportion of patients with flail segment, and being a single centre study [59].

Conclusions

This review supports the use of POCUS in diagnosing rib fractures which can be extended into ultrasound guided procedures of pain control of rib fractures. Nevertheless, it highlights the need for research with higher quality and strong evidence to refine its role. Ultrasound and CT scan should be seen as complementary diagnostic studies and not competitive. Recognizing the advantages and limitations of each will help selecting the best diagnostic modality tailored for a specific clinical situation.

Abbreviations

CT	Computed tomography
CXR	Chest X-ray
ESPB	Erector spinae plane block
ICNB	Intercoastal nerve block
POCUS	Point-of-care ultrasound
SAPB	Serratus anterior plane block

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Author contributions

All authors have contributed to the idea. Abu-Zidan F supervised the project, did the literature search, retrieved the literature, structured the review, allocated the tasks, critically read and wrote the sections on introduction, methods, basic physics, technical considerations, and contributed to other sections, prepared the images, repeatedly edited the manuscript and prepared it for final submission. Alao DO critically read and wrote the sections on experimental models, artificial intelligence, and ultrasound guided procedures. Cevik AA critically read and wrote the sections on sonographic findings of rib fractures, advantages and disadvantages of POCUS, and diagnostic accuracy of ultrasound. All authors approved the final version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The simulated patient shown in Fig. 2 signed a consent form approving using his clinical images in medical publication. Two images (Figs. 5 and 6) were taken from open access journals. All other radiological images were anonymous.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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